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Research Article

Specimen Test of Large-Heat-Input Fusion Welding Method for Use of SM570TMCP

Dongkyu Lee[1] and Soomi Shin[2]

[1] *Department of Architectural Engineering, Sejong University, 98 Gunja-dong, Gwangjin-gu, Seoul 143-747, Republic of Korea*
[2] *Research Institute of Industrial Technology, Pusan National University, Jangjeon-dong, Gumjeong-gu, Busan 609-735, Republic of Korea*

Correspondence should be addressed to Soomi Shin; shinsumi82@pusan.ac.kr

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In this research, the large-heat-input welding conditions optimized to use the rear plate and the high-performance steel of SM570TMCP, a new kind of steel suitable for the requirements of prospective customers, are proposed. The goal of this research is to contribute to securing the welding fabrication optimized to use the high-strength steel and rear steel plates in the field of construction industry in the future. This research is judged to contribute to securing the welding fabrication optimized to use the high-strength steel and rear steel plates in the field of construction industry in the future.

1. Introduction

Since the rigidity and strength required for members increase according to recent trends of the large space and high rise such as diagrid [1–4] of architectural structures and the large span of steel bridges, steel materials gradually tend to aim at high strength, extremely thick plate, and high performance, and its application is introduced by Schroeter and Lehnert [5]. Such steel materials, while structured, require mutual connection between members and inevitably accompany welding during the work. Thus, in order to secure the safety of structures and the efficiency of work, it is essential to improve welding quality and secure reliability.

According to the questionnaire survey conducted by Korea Research on the basis of a contract with POSCO and Research Institute of Industrial Science and Technology (RIST) regarding the demand analysis of high-performance steel types [6] targeting over 500 experts from academia, structural designers, and construction companies, most of the experts preferred, as performance standards of high-performance steel kinds, (i) a high design standard strength; (ii) no reduction in the design standard strength in the over 40 mm thickness; and (iii) excellent weldability. Out of these preferences, the first and second preferences are fundamental requirements which may cause troubles in securing the expected performance of steel kinds, while the third one may be regarded as a secondary requirement which can be preferentially improved on the basis of the weldability data of existing general steels.

In response to such requirements, POSCO has developed PILAC-BT45 steel in 2004, which is denoted as SM570TMC, a 600 MPa-class new steel material, for application to architectural structures, whose weldability is improved by reducing the carbon equivalent a great deal, while raising the design standard strength of steel materials, with the thermomechanically controlled (TMC) process. As representative researches related to SM570TMC, Chang et al. [7] introduced experimental and numerical investigations on residual stresses of SM570TMC. Lee et al. [8] provided characteristics of high temperature tensile properties and residual stresses in welded joints.

In general, for high strength and extremely thick steel materials, alloying elements are added, which accompanies the quality nonuniformity of steel materials. In the welding work of using such steel materials, the reduction in the welding constructability and the structural performance of welded areas has been known to be inevitable. Lately, in case of fabricating steel structures, the application of such a large-heat-input welding method for which Kojima et al. [9] developed high HAZ toughness steel plates of box columns,

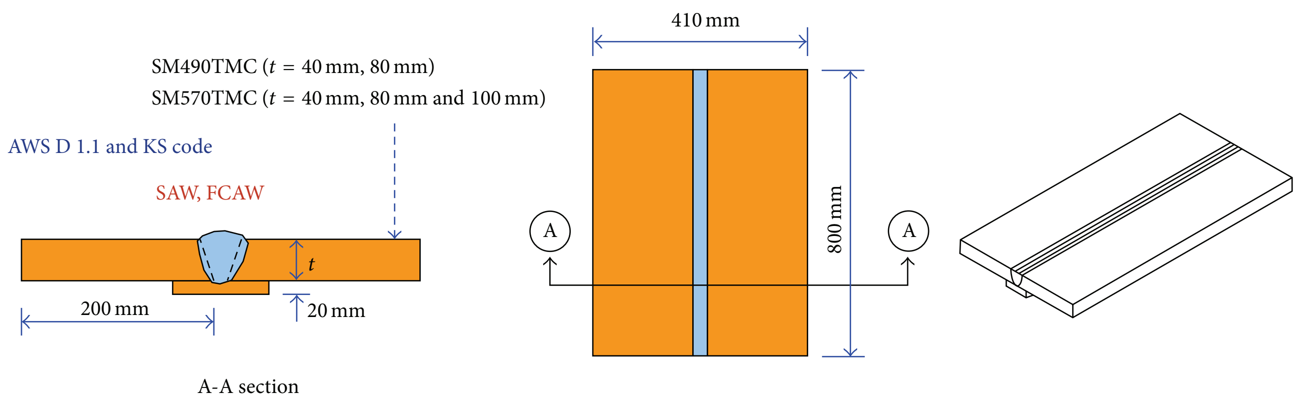


Figure 1: Welding test steel plate before being cut.

as SAW, has increased to improve the productivity. In case of applying steel types of high strength and extremely thick plate under increasing demand, the verification of such weldability is always essential. The rear plate is mostly used as a structure assembled by cutting and welding and so its weldability should sufficiently be considered. In addition, in case of welding at low temperatures, the welding method should also be reviewed. Meanwhile, though the large-heat-input welding method has an advantage that it improves work efficiency, the amount of heat input, groove shape, and welding method should be sufficiently reviewed in selecting large-heat-input steel materials.

In this research, experiments were conducted by taking the amount of heat input, including the numerical value specified for the rear plate by the fabricator, and the kind of steel (SM490TMC, SM570TMC) as variables and applying the welding methods of ESW, SAW, and FCAW, in which Kou [10] dealt with fusion welding processes of steel, Schwartz [11] described metal joining manual in advance, and Song et al. [12] introduced single-side resistance spot welding as a basis of welding methods, and the large-heat-input welding conditions are presented in accordance with the experimental results. SM570TMC as newly high strength steel is alternative which is the most appropriate to build mega steel structures, as it may save material quantity such as reduction of steel thickness. For the purpose, it is necessary to execute large-heat-input welding, but there is rarely detailed information of the welding condition of SM570TMC.

In this research, in order to present the optimum large-heat-input welding conditions of SM570TMC high-performance steel, the following sequential verification processes were performed in comparison with the existing characteristics of SM490TMC: cutting inspection of steel materials, review of existing welding conditions, amount of heat input for SAW and FCAW, establishment and verification of large-heat-input welding conditions through tensile, flexural, impact, macro, and hardness performance experiments, and preparation of large-heat-input welding manual.

2. Fabrication of Large Heat Input Test Specimen

2.1. Fabrication of Welding Specimen for SAW and FCAW Welding Test. Thick steel plates are basically used as the steel plates for large-heat-input welding test specimen for SAW and FCAW [13]. The thicknesses of SM490TMCP 40 mm and 80 mm and SM570TMCP steels are 40 mm, 80 mm, and 100 mm, respectively. For welding parts, single V Groove, root opening 10 mm, root face 0, and angle 30° are applied. For preheating [14], normal temperature is applied to specimen with thickness below 50 mm, and temperature above 50°C is applied to thickness 100 mm, respectively. Welding test steel plates, shapes of welding specimen, and specification of specimen are in accordance with AWS D 1.1 and KS D 3503 code [15], and these are shown in Figures 1 and 2, respectively.

2.2. Fabrication of ESW Welding Specimen. Thick steel plates are basically used as the steel plates for large-heat-input welding test specimen for ESW. The thicknesses of SM490TMCP and SM570TMCP steels are 35 mm. Welding parts details are in accordance with AWS D 1.1 and KS code, which are shown in Figure 3.

For ESW, a CES welding machine as shown in Figure 4(a) is used, and its status of attachment before welding and after welding are shown in Figures 4(b) and 4(c).

3. Experimental Results of Large-Heat-Input Welding Specimen

3.1. Large-Heat-Input Welding Test Details and Test Set-Up Procedures. As a consideration during planning of large-heat-input welding, it is necessary to confirm the weldable thickness in case of ESW [16, 17]. For the case of TAG Company of Japan, in case of using two nozzles, a weldable thickness of 100 mm has been reported to be feasible. In Korea, the optimum weldable thickness of CES welder [18] is 60 mm, the limit of quality assurance. In this research, the thickness of parent materials is based on 35 mm.

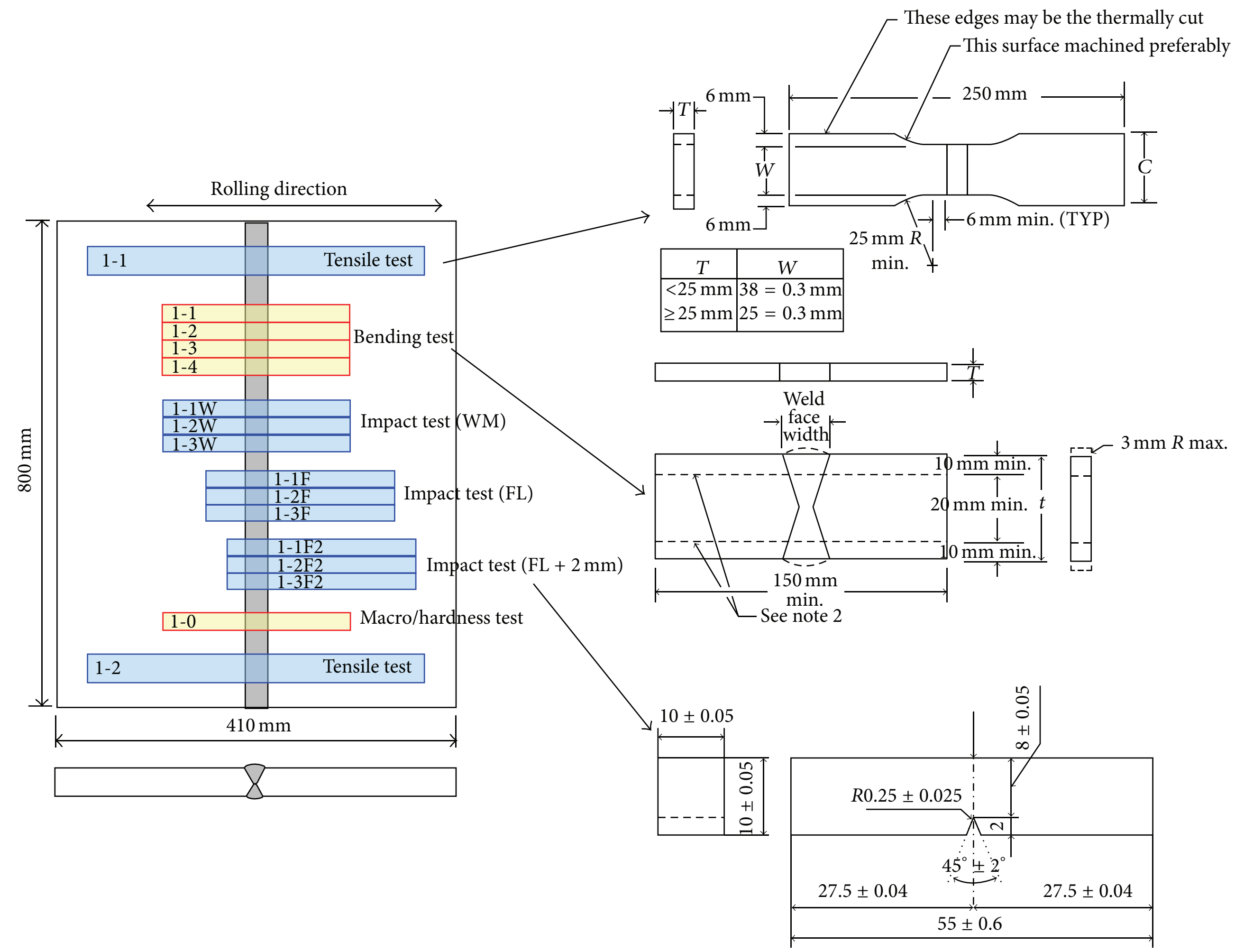


Figure 2: Welding specimen collection drawing and their shape.

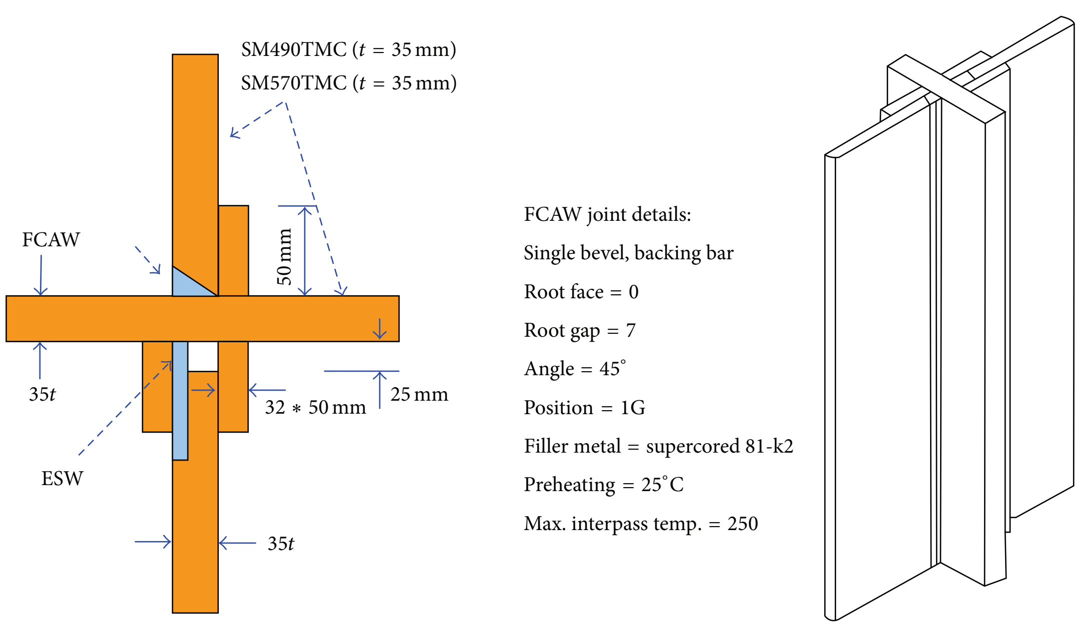


Figure 3: Welding test steel plate before being cut.

(a) CES welding machine (b) Status of attachment before welding

(c) Status of attachment after welding

Figure 4: ESW welding status.

Table 1: Large-heat-input welding test conditions.

Welding process	Amount of welding heat input	Welding materials	Thickness of parent material	Details of welded areas and welding posture
(i) Consider the welding methods used mainly in fabricating the members and joints of architectural structures. ex) Large-heat-input welding: SAW, FCAW, ESW	(i) Fix current and voltage. (ii) Control the amount of welding heat input by varying the welding speed.	(i) Depending on the chemical composition of welding materials, affected are the deposited metal by large-heat-input welding and the embrittlement of HAZ part. (ii) Consider the application to welding rod products.	(i) In general, the thicker the base materials get, cracks may be created due to the increase in the degree of constraints for welded areas and the contraction stress. (ii) Apply to 35 mm, 40 mm, 80 mm, and 100 mm rear plates.	(i) AWS D 1.1. Apply standard welding details to V/dam welding (35 mm, 40 mm) and X-type groove welding (80 mm, 100 mm) examined in advance in the standard specifications of architectural construction. (ii) The welding posture is 1 G.

The conditions of large-heat-input welding tests established on the basis of the above contents in this research are given in Table 1.

Large-heat-input welding test according to AWS D 1.1 [19] includes visual inspection, NDE, cutting inspection, sectional tensile test, side face bending test, impact test, and macro and hardness test. Test types carried out in this study are summarized in Table 2.

Tables 3 and 4 show the specimens for large-heat-input welding of SM490TMCP and SM570TMCP which are carried out in this study.

3.2. Tensile Test Results. The results for tensile tests of large-heat-input welding for SM490TMCP and SM570TMCP are shown in Tables 5 and 6, respectively. In case of ESW, SM570TMCP requires 1.5 to 2 times the amount of heat input of SM570TMCP and has shown satisfactory yield strength. The elongation at break of SM570TMCP, high strength steel, is found to be about 25, lower than that of SM490TMCP 33, a general steel type.

It has been found that, in case of SAW, an automatic welding, at the same amount of heat input of 50 or 70 KJ/cm, as the plate thickness of SM490TMCP increases from 40 mm to 80 mm, the tensile strength falls from about 550 to about 520. It has also been found that, at the same amount of heat input of 70 KJ/cm, as the plate thickness of SM570TMCP increases from 40 mm to 80 mm, the tensile strength falls from about 660 to about 620. Therefore, in case of SAW, it is judged that as the thickness increases, it is necessary to increase the amount of heat input from 70 to about 100 in the aspect of securing the safety of welded areas.

Table 2: Test types of large-heat-input welding.

Test item	Test method	Specimen Quantity	Judgment criteria
Visual inspection	Visual	—	Good bead appearance on surface/no undercut nor blow hole
Nondestructive examination	UT	—	There is no internal crack (high temperature crack and low temperature crack) on welded metal and HAZ part, impurity, nor discontinuity
Cutting inspection	Architectural work standard specification	1	(i) Roughness on cut surface: refer to 4.2 (ii) Cut deformation: refer to 4.3
Sectional tensile test	KS B 0833	2	Tensile strength will be above the specified value of base metal.
Side face bending test	KS B 0832	4	Cracked length on welded part when bent in 180° will be below the value required by KS B 0832.
Impact test (0, −5, −20°C) Heat affected part (HAZ) Welded metal part (WM) Weld metal part FL	KS B 0810	 3 3 3	The value of welded metal will be above the specified value of base metal. *Target steel type* / *Test temp.* / *Criteria* SM490TMC / 0°C / 27 J or above SM570TMC / −5°C / 47 J or above
Macro/hardness test	—	1	There is no crack nor deficiency on welded metal part and HAZ part. Hardness on welded metal part and HAZ part will be above the value required by KS/architectural work standard specification.

Table 3: Large-heat-input welding test details and specimens (SM490TMCP).

Steel type	Plate thickness (mm)	Preheat tem. (°C)	Interlayer tem. (°C)	Welding method	Input heat (kJ/cm)	Voltage (V)	Current (A)	Speed (Cm/min)	Welding materials	
SM490 TMCP	35	None	None	ESW	61	40 ± 5	380 ± 10	15	KD-50	
		None	None		56	45 ± 5	380 ± 10	18	KD-50	
	40	None	Max. 250°C	SAW	50	DC	DC		Welding rod	Flux
						1st: 22~30 2nd: 26~34 3rd: 28~36	1st: 510~540 2nd: 580~640 3rd: 560~620	1st: 22~30 2nd: 34~42 3rd: 36~40	Korea KD60	EF260
		None	Max. 250°C		70			Same for SAW		
		None	Max. 250°C	FCAW	50	1st: 20~26 2nd: 26~34 3rd: 22~30	1st: 138~155 2nd: 180~220 3rd: 160~200	1st: 6~12 2nd: 10~18 3rd: 12~20	Hyundai Supercored 81-k2	
	80	50°C	Max. 250°C	SAW	50			Same for SAW		
		50°C	Max. 250°C		70			Same for SAW		
		50°C	Max. 250°C	FCAW	Dangjin (50)		Same for FCAW		Hyundai Supercored 81-k2	

Table 4: Large-heat-input welding test details and specimens (SM570TMCP).

Steel type	Plate thickness (mm)	Preheat tem. (°C)	Interlayer tem. (°C)	Welding method	Input heat (kJ/cm)	Voltage (V)	Current (A)	Speed (Cm/min)	Welding materials	
SM570 TMCP	35	None	None	ESW	80	45 ± 5	390 ± 10	12	KD-60	
		None	None		120	50 ± 5	400 ± 10	11	KD-60	
	40					DC	DC		Welding rod	Flux
		50°C	Max. 250°C	SAW	70	1st: 22~30 2nd: 26~36 3rd: 28~34	1st: 660~740 2nd: 760~840 3rd: 760~860	1st: 60~67 2nd: 66~78 3rd: 64~76	Korea KD60 Hyundai A-3	EF260 S800MX
		50°C	Max. 250°C		100			Same for SAW		
		50°C	Max. 250°C	FCAW	60	1st: 20~28 2nd: 24~32 3rd: 22~30	1st: 148~154 2nd: 160~260 3rd: 158~240	1st: 7~12 2nd: 16~22 3rd: 14~20	Hyundai supercored 81-k2	
	80	50°C	Max. 250°C	SAW	70			Same for SAW		
		50°C	Max. 250°C	FCAW	60			Same in case of FCAW welding		
	100	50°C	Max. 250°C	SAW	70			Same for SAW		
		50°C	Max. 250°C	FCAW	60			Same in case of FCAW welding		

Table 5: Results of tensile test in large-heat-input welding test (SM490TMCP).

Steel type	Plate thickness (mm)	Preheat tem. (°C)	Interlayer tem. (°C)	Welding method	Input heat (kJ/cm)	Yield strength (0.2%, MPa)	Tensile strength (MPa)	Elongation (%)	Fracture part
SM490TMC	35	None	None	ESW	61	354	558	33.4	Weld Metal
						354	532	32.7	Base Metal
					56	342	518	31.7	Weld Metal
						352	563	35.5	Weld Metal
	40	None	Max. 250°C	SAW	50	411	557	27.5	Base Metal
						404	557	31.3	Base Metal
					70	355	555	29.9	Base Metal
						405	561	31.4	Base Metal
				FCAW	50	419	553	21.3	Base Metal
						416	574	23.0	Weld Metal
	80	50°C	Max. 250°C	SAW	50	339	523	34.2	Base Metal
						336	513	35.8	Base Metal
					70	342	519	34.2	Base Metal
						355	529	35.8	Base Metal
				FCAW	50	348	528	28.1	Base Metal
						344	527	30.0	Base Metal

Table 6: Results of tensile test in large-heat-input welding test (SM570TMCP).

Steel type	Plate thickness (mm)	Preheat tem. (°C)	Interlayer tem. (°C)	Welding method	Input heat (kJ/cm)	Yield strength (0.2%, MPa)	Tensile strength (MPa)	Elongation (%)	Fracture part
SM570TMC	35	None	None	ESW	80	445	610	25.2	Weld Metal
						460	624	26.5	Weld Metal
					120	456	616	22.4	Weld Metal
						466	625	24.5	Weld Metal
	40	50°C	Max. 250°C	SAW	70	579	660	22.6	Weld Metal
						583	655	24.2	Weld Metal
					100	567	652	19.3	Weld Metal
						530	648	22.7	Weld Metal
				FCAW	60	535	606	19.1	Weld Metal
						531	407	15.9	Weld Metal
	80	50°C	Max. 250°C	SAW	70	452	611	29.8	Base Metal
						455	627	34.0	Base Metal
				FCAW	60	532	604	25.5	Weld Metal
						529	589	29.7	Weld Metal
	100	50°C	Max. 250°C	SAW	70	554	627	23.3	Weld Metal
						561	639	36.0	Base Metal
				FCAW	60	499	597	22.7	Weld Metal
						502	596	22.5	Weld Metal

In case of FCAW, a semiautomatic welding, both SM490TMCP and SM570TMCP show the tensile strength without deviations regardless of the plate thickness, demonstrating the performance stability for welding fabrication of specimens. And, in all cases, breakups occurred at the base or welded areas.

Figure 5 shows the tensile test result of SAW and FCAW for SM570TMCP with the thickness of 80 mm and 100 mm. As can be seen, all tensile test specimens collapse at the welding part, not the parent metal part, after making plastic hinge behaviors. It verifies the superiority of welding connections.

3.3. Side Face Bending Test Results. According to varying input heat and thickness, side face bending test results of SM490TMCP and SM570TMCP are shown in Figure 6. These results are satisfactory in general; however, welding defects are found in SM490TMCP-40 mm-SAW input heat 70 and it shows manufacturing defect of the specimen.

As can be seen in Figures 6(a), 6(d), and 6(f), large heat input of 70 can be used for the thick and high strength SM570TMCP specimen of SAW, but SM490TMCP of SAW may produce welding error owing to too large heat input and relatively thin specimen condition.

(a) SM570TMCP-80 mm-SAW

(b) SM570TMCP-80 mm-FCAW

(c) SM570TMCP-100 mm-SAW

(d) SM570TMCP-100 mm-FCAW

Figure 5: Tensile test result of SAW and FCAW for SM570TMCP 80 mm and 100 mm.

(a) SM570-80 mm-SAW input heat 70

(b) SM490-35 mm-ESW input heat 60

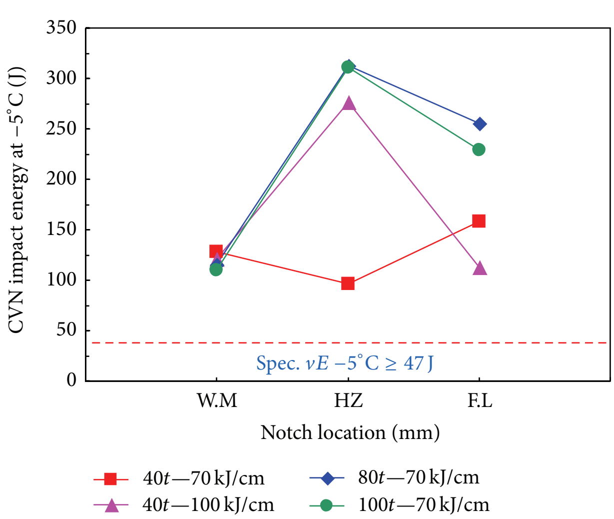
(c) SM570-35 mm-ESW input heat 80

(d) SM490-40 mm-SAW input heat 70

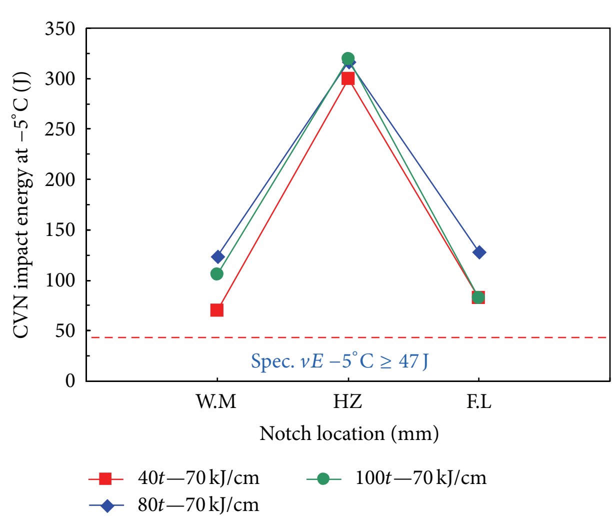
(e) SM490-80 mm-FCAW input heat 50

(f) SM490-40 mm-SAW input heat 70

Figure 6: Side face bending test result of SM490TMCP and SM570TMCP.

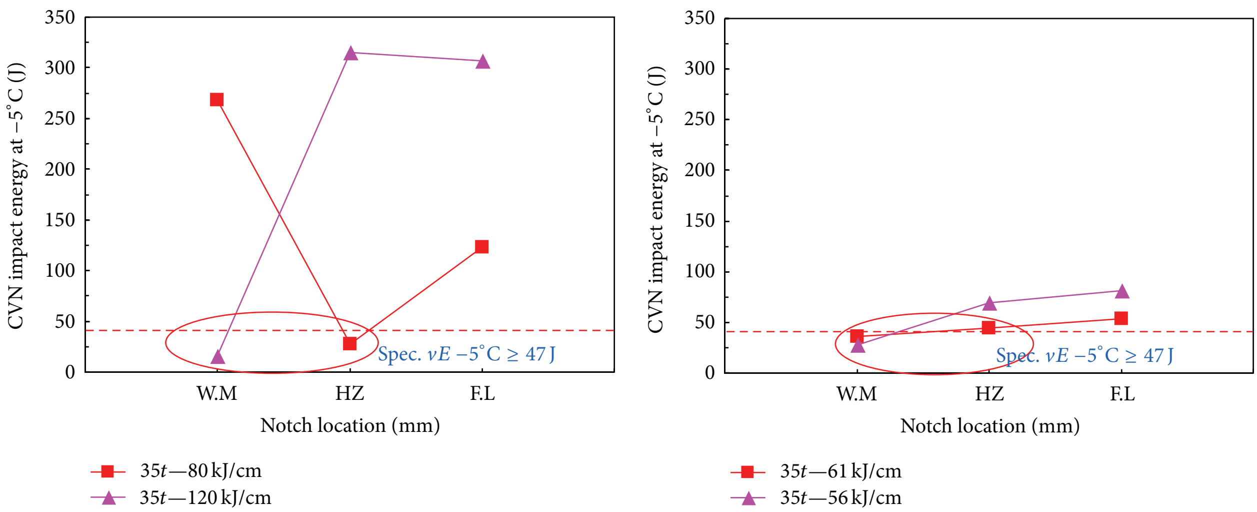


(a) SAW



(b) FCAW

Figure 7: Impact test result of SM570TMCP welding part.



(a) SM570TMCP of ESW

(b) SM490TMCP of ESW

FIGURE 8: Impact test result of SM570TMCP and SM490TMCP welding part.

(a) SM570TMCP-40 mm-SAW

(b) SM570TMCP-40 mm-FCAW

FIGURE 9: Impact test result of SAW and FCAW for SM570TMCP 40 mm.

SM570TMC ESW (120 kJ/cm)

SM490TMC ESW (56 kJ/cm)

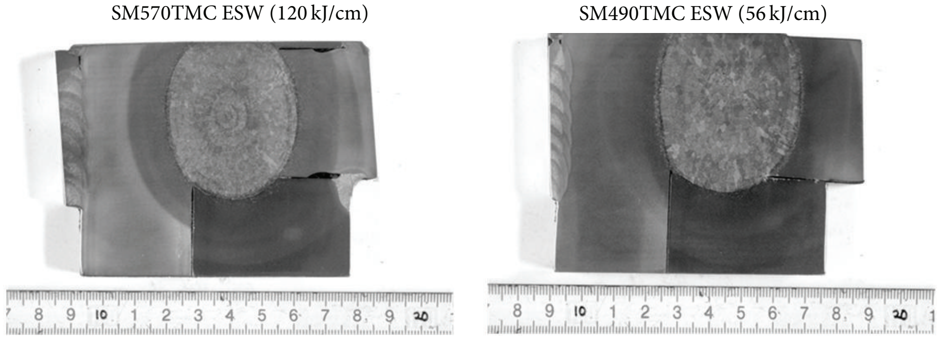
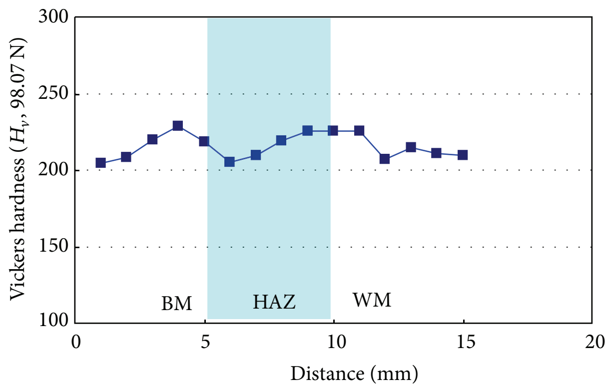


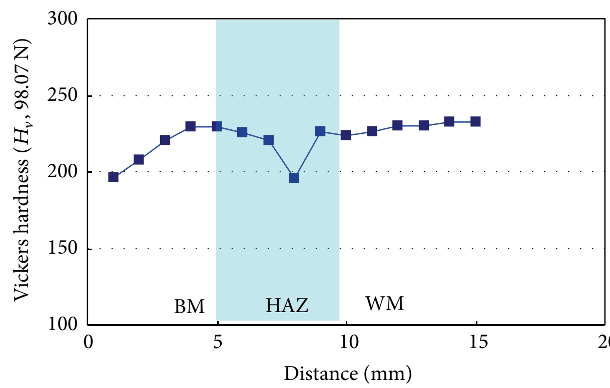
FIGURE 10: Macro test result of ESW welding for SM490TMCP and SM570TMCP.

3.4. Impact Test Results. Charpy impact characteristics of welding parts of weld metal (WM), hard zone (HZ), and fusion line (FL), in case SM570TMCP for both SAW and FCAW meet the requirements in the standards of the red dash line, which are shown in Figure 7. As can be seen, SM570TMCP with thickness of 100 mm also produces large impact energy at WM, HZ, and FL.

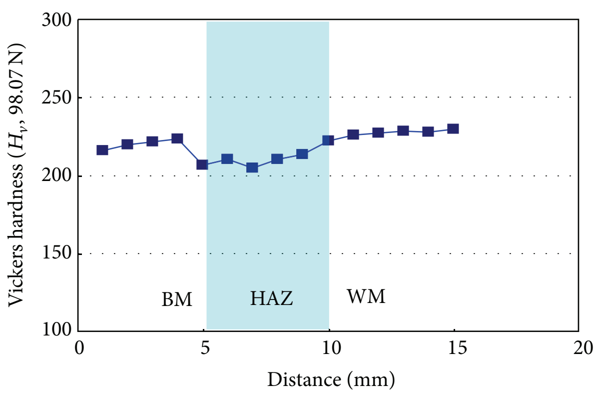
Figure 8 shows impact energies of SM570TMCP and SM490TMCP of ESW at WM, HZ, and PL. As can be seen, impact energies of WM and HZ of the red circle line are not satisfactory to the standards. It can be found that welding conditions such as heat input, in especial, for ESW should be controlled to take manufacturing quality, regardless of steel type.



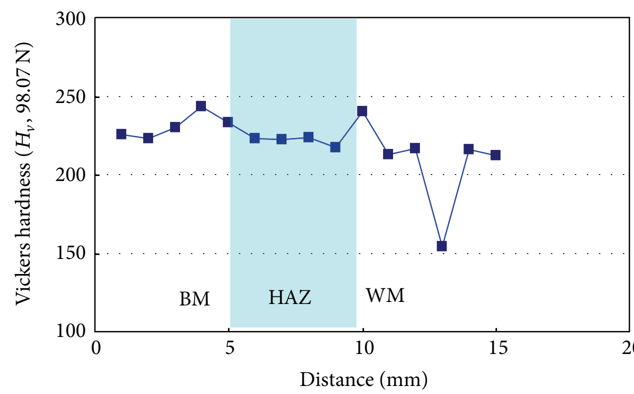
(a) SM570-40 mm-SAW (70 kJ/cm)



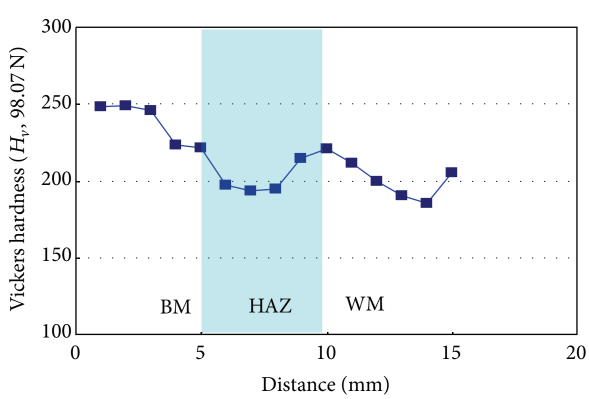
(b) SM570-40 mm-SAW (100 kJ/cm)



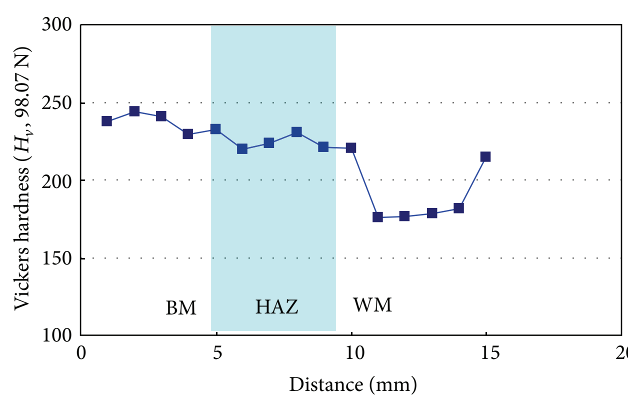
(c) SM570-80 mm-SAW (70 kJ/cm)



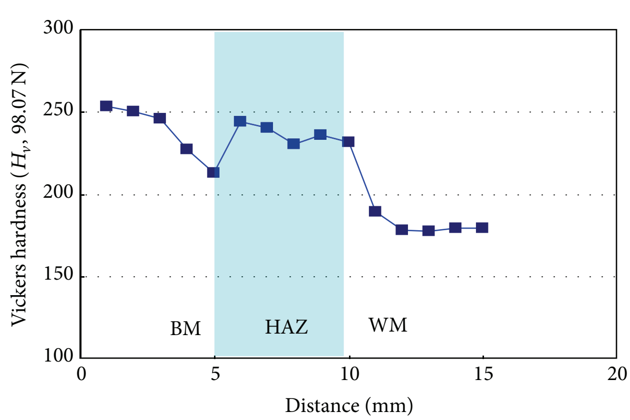
(d) SM570-100 mm-SAW (70 kJ/cm)



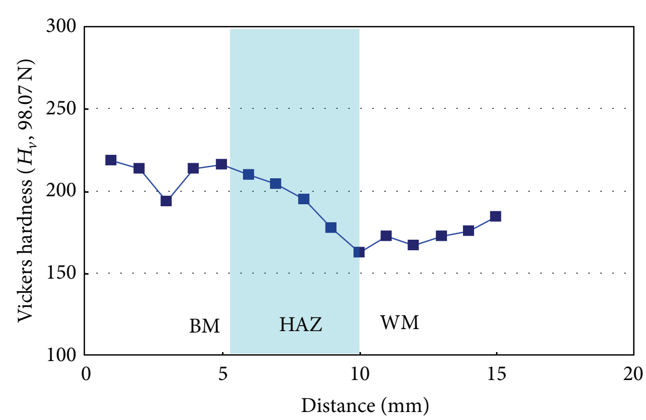
(e) SM570-40 mm-FCAW (60 kJ/cm)



(f) SM570-80 mm-FCAW (60 kJ/cm)

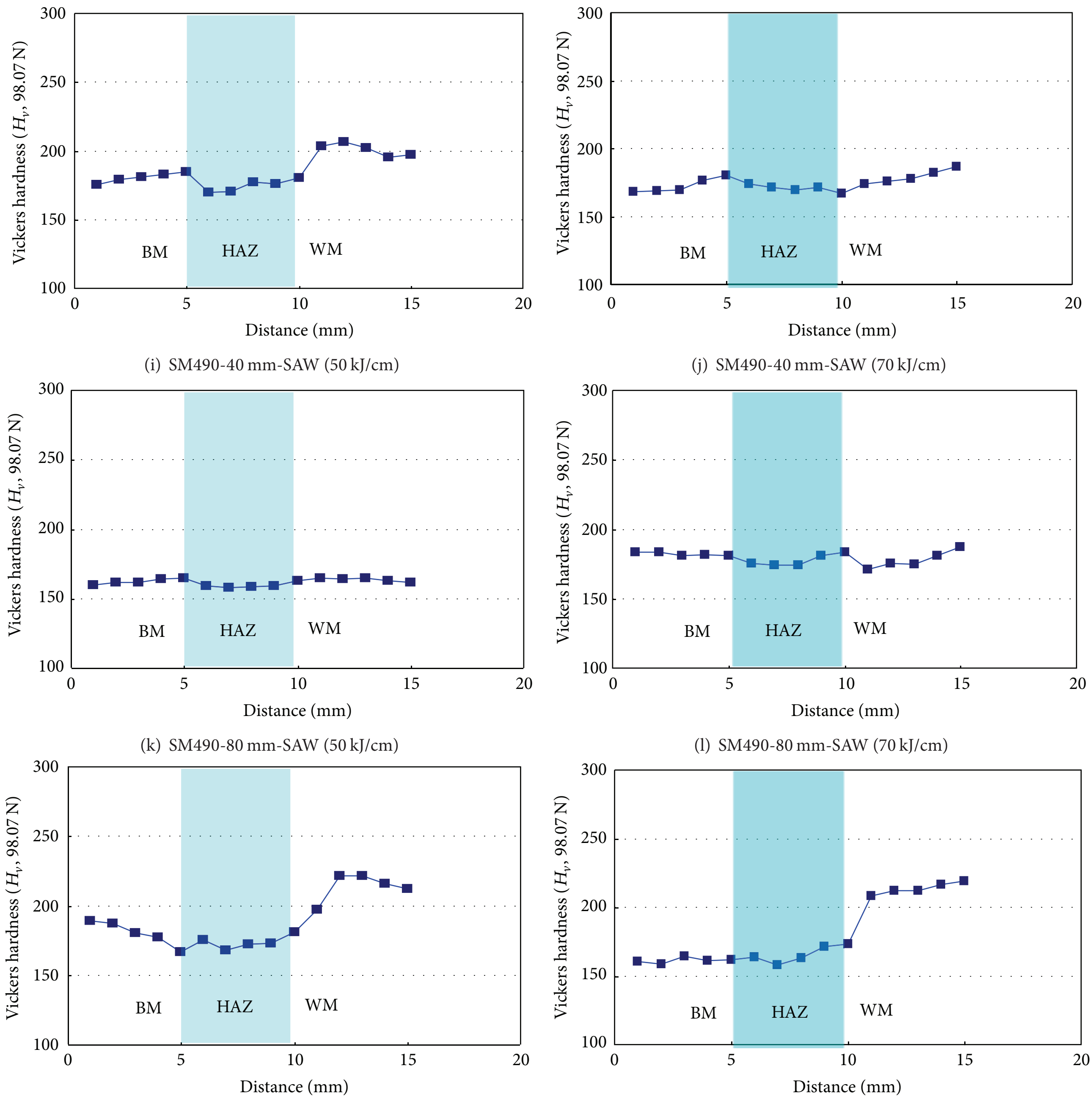


(g) SM570-100 mm-FCAW (60 kJ/cm)



(h) SM570-35 mm-ESW (60 kJ/cm)

FIGURE 11: Continued.



(i) SM490-40 mm-SAW (50 kJ/cm)
(j) SM490-40 mm-SAW (70 kJ/cm)
(k) SM490-80 mm-SAW (50 kJ/cm)
(l) SM490-80 mm-SAW (70 kJ/cm)
(m) SM490-40 mm-FCAW (50 kJ/cm)
(n) SM490-80 mm-FCAW (50 kJ/cm)

Figure 11: Hardness test results of SAW, FCAW, and ESW welding for SM490TMCP and SM570TMCP.

Figure 9 shows the impact test result of SM570TMCP specimen. Requested requirements by the standard are those for SM490TMCP 27 J and, SM570TMCP 47 J.

3.5. Results for Macro and Hardness Tests. The cross sections of specimens for macro test results of ESW welding for SM490TMCP and SM570TMCP, to which heat input amounts (kJ/cm) of 56 and 120, respectively, were applied, are shown in Figure 10.

Figure 11 shows the results for hardness distribution of the base metal (BM), HAZ, and welded metal (WM) areas during SAW, FCAW, and ESW welding of SM490TMCP and SM570TMCP. As shown in Figure 11, in case the amounts of heat input for SM570TMCP and SM490TMCP are large, the upper limit of hardness for HAZ part turned out to be large, and in case the amount of heat input are the same, the thicker the plate, the larger the calculated hardness value. It is natural to obtain these results, which means that the provided welding conditions are appropriate overall, demonstrating that the welding fabrication by SAW, FCAW, and ESW is excellent.

4. Conclusions and Remarks

In this research, embodied are the proper welding conditions of large-heat-input welding as an efficient welding method for performance improvement required for high strength and high performance of architectural steel materials. Welding fabrication tests were conducted for SM490TMCP, a steel kind which is in general used a lot, and SM570TMCP, high strength steel. An optimum amount of heat input, especially, was quantitatively analyzed for the case of rear plates with high strength properties.

In this research, conducted was the performance evaluation of the welded areas based on the welding fabrication methods of SAW, FCAW, and ESW, and proposed are the large-heat-input welding conditions optimized to use the rear plates and high performance steel of SM570TMCP, a new steel kind suitable for the requirements of prospective customers.

In especial, welding conditions such as heat input for ESW including SAW and FCAW have to be controlled to take manufacturing quality, regardless of steel type. Large-heat-input condition can be appropriately used for the thick and high strength SM570TMCP steel construction, but normal strength steel such as SM490TMCP may produce welding error owing to too large heat input and relatively thin thickness condition.

This research is judged to contribute to securing the welding fabrication optimized to use the high strength steel and rear steel plates in the field of construction industry in the future.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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